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ORIGINAL ARTICLE

Vascular effects of a single high salt meal

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KEYWORDS

Endothelial function;
Resistive index;
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Abstract *Background:* High salt intakes are associated with a greater incidence of strokes and cardiovascular events. Increased dietary salt for a long time impairs endothelial function. However, the immediate effect of only one high salt meal is not fully elucidated.

Aim of study: To detect vascular responses of a group of healthy adults to a single high-salt meal.

Subjects and methods: 63 volunteers (35 male and 28 female) aged 21–40 years were subjected to measurement of office blood pressure, plasma sodium, flow mediated dilatation and both resistive (RI) and pulsatility (PI) indices of renal as well as carotid arteries at baseline (fasting 8 h over night and only water is allowed) and 60 min after consumption of high sodium soup containing 4 g salt (equal to 68 mmol Na).

Results: There is significant increase in FMD as well as the resistive and pulsatility indices of both the carotid and femoral arteries after ingestion of the test meal compared to before meal ($P < 0.001$). Blood pressure is increased in the post-prandial phase but no correlation detected with these parameters ($P = 0.89$, 0.61 & 0.73 for carotid, 0.43 & 0.74 for renal). Plasma sodium increased after high salt meal (mean ± SD = 1.32 ± 0.83) and correlated with carotid PI ($P = 0.0001$).

Conclusion: High salt intake may acutely impair vascular function in different vascular beds independent of the increase of blood pressure. Plasma sodium increase may be one of the underlying mechanisms.

1. Introduction

Metabolic abnormalities in the postprandial state are known to contribute to endothelial dysfunction and atherosclerosis progression in healthy people.[1]

It has become increasingly clear that high dietary salt intakes are associated with a greater incidence of strokes and cardiovascular events[2] that is independent of its well-known ability to increase arterial pressure in some individuals.[3]

Endothelial dysfunction that is considered to be an initial step in the development of atherosclerosis[4], has been reported with chronic higher salt intakes.[5] Recently, it was proved that high salt diet impairs brachial artery FMD to a similar extent in adults with salt sensitive blood pressure and salt resistant blood pressure.[6]

Increased vascular stiffness is an early change in atherosclerosis.[7] An increase in the pulsatility index (PI) has been suggested to reflect distal vascular resistance.[8]

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The resistive index (RI) of the carotid artery which is a hemodynamic parameter that depends on the degree of vascular resistance can be assessed as a surrogate marker of generalized atherosclerosis[9] while the carotid pulsatility index (PI) was shown to be associated with several diseases such as microangiopathy in cerebral vessels[10,11] and significantly correlated with Framingham risk scores in subjects with hypertension.[11] Furthermore, systemic artery stiffness is correlated with carotid artery stiffness.[12]

Intrarenal resistance indices are a complex integration of arterial compliance, pulsatility, and peripheral resistance. They are associated with traditional cardiovascular risk factors as well as with subclinical atherosclerotic vessel damage.[13] The pulsatility index (PI) and the resistive index (RI) are used as pulsed-wave Doppler measurements of downstream renal artery resistance.[14] Recently, renal resistive index is considered as a marker of systemic vascular changes.[15]

However, the acute effect of single high salt diet is not fully elucidated.

2. Aim of the work

To detect vascular responses of a group of healthy adults to a single high-salt meal.

3. Subjects and methods

This study was carried out in cardiology department at El Minya University Hospital, Minya, Egypt, over the period between December 2013 and March 2015.

63 volunteers (35 males and 28 females) aged 21–40 years were recruited and included in this study after giving written informed consent.

Inclusion criteria were body mass index (BMI; in kg/m^2) $\geqslant 18$ and $\leqslant 25$, systolic BP (SBP) < 130 mm Hg, and diastolic BP (DBP) < 90 mm Hg.

4. Exclusion criteria

Exclusion criteria included atherosclerotic complications such as stroke and myocardial infarction; those undergoing hemodialysis, patients with peripheral vascular disease, malignancy, infections, hypertensive and diabetic patients were excluded.

All subjects were subjected to measurement of office blood pressure, plasma sodium, flow mediated dilatation and both resistive and pulsatility indices of renal as well as carotid arteries at baseline (fasting 8 h over night and only water is allowed) and 60 min after consumption of high sodium soup (prepared by member of public health and preventive medicine) containing 4 g salt (equal to 68 mmol Na).

Measurement of blood pressure (BP): seated BP was measured with an automated sphygmomanometer while fasting. Four consecutive BP measurements were taken 1 min apart. The first reading was discarded, and the mean of the next 3 consecutive readings with SBP readings within 10 mm Hg and DBP within 5 mm Hg of each other was taken as the fasting measurement. Blood pressure measurement was repeated 60 min after consumption of test meal.[16]

Endothelial function: to assess endothelial function non-invasively with B-mode ultrasound, conduit vessel endothelium-dependent vasodilatation was induced by reactive hyperemia, while endothelium-independent vasodilatation was induced by administration of sublingual nitroglycerine (glyceryl trinitrate; GTN).[17]

Measurements were made of changes in the diameter of the brachial artery using a pulsed wave Doppler with 7 MHz probe. The ultrasound examination was performed in quiet room at temperature between 21 °C and 32 °C. Subjects rested in a supine position for 15 min before examination. A B-mode scan was obtained of the right brachial artery in longitudinal section. A resting measurement was taken and called pre-flow mediated dilatation (pre-FMD), and a pneumatic cuff was then inflated to a pressure of 200 mm Hg for 5 min, then the diameter of the artery was recorded again 45–60 s after deflation (post-FMD) (Fig. 1). A period of 15 min was allowed for recovery before testing for endothelium-independent relaxation. A repeat baseline measurement of the diameter was taken before a 400 ug dose of sublingual GTN spray was administrated (pre-GTN). The brachial artery diameter was again measured 3–4 min after the GTN was given (post-GTN).[18]

FMD, GTN, and dilatation ratio were calculated as follows:

$$\text{FMD} = (\text{Post-FMD} - \text{Pre-FMD})/\text{Pre-FMD} \times 100.$$
$$\text{GTN} - \text{MD\%} = (\text{Post-GTN} - \text{Pre-GTN})/\text{Pre-GTN} \times 100.$$
$$\text{Dilatation ratio} = \text{FMD}/\text{GTN} - \text{MD\%} \times 100.$$

Duplex examination of the carotid arteries: ultrasound examination was performed while the patient was in a supine position. In all patients, routine carotid US examinations including gray-scale and color and pulsed Doppler ultrasound examinations of the left and right common carotid arteries (CCAs) and internal carotid arteries (ICAs) were conducted. All measurements were made by using angle correction. The peak systolic velocity (PSV), end-diastolic velocity (EDV), resistive index (RI), and pulsatility index (PI) were calculated.[19]

As regards the duplex examination of the renal arteries: duplex examination of both renal arteries with measurement

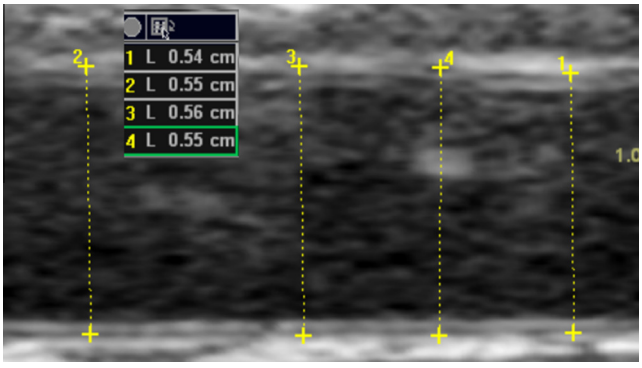

Fig. 1 Ultrasonographic measurement of brachial artery diameter.

Table 1 Effect of high salt meal.

	Before meal	After meal	*P* value
Renal artery RI			
Range	(0.5–0.72)	(0.53–0.74)	< 0.001*
Mean ± SD	0.62 ± 0.05	0.64 ± 0.05	
Renal artery PI			
Range	(0.64–1.14)	(0.66–1.27)	< 0.001*
Mean ± SD	0.92 ± 0.09	0.96 ± 0.11	
Carotid artery RI			
Range	(0.45–0.69)	(0.47–0.75)	< 0.001*
Mean ± SD	0.61 ± 0.04	0.63 ± 0.05	
Carotid artery PI			
Range	(0.59–1.09)	(0.6–1.2)	< 0.001*
Mean ± SD	0.9 ± 0.09	0.96 ± 0.11	
FMD			
Range	(5.33–34.15)	(4.36–31.45)	< 0.001*
Mean ± SD	15.91 ± 7.28	14.11 ± 6.37	
SBP (mm Hg)			
Range	(112–136)	(115–138)	< 0.001*
Mean ± SD	124.53 ± 6.56	126.53 ± 6.27	
DBP (mm Hg)			
Range	(63–90)	(65–94)	< 0.001*
Mean ± SD	77.71 ± 4.84	80 ± 4.73	
MAP (mm Hg)			
Range	(80.33–103)	(82.67–107.67)	< 0.001*
Mean ± SD	93.32 ± 4.6	95.51 ± 4.49	
Na (mmol/dl)			
Range	(135–140)	(136–141)	< 0.001*
Mean ± SD	136.81 ± 1.11	138.61 ± 1.44	

RI: resistive index, PI: pulsatility index, Na: plasma sodium level, FMD: flow mediated dilatation, SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean blood pressure.
* Significant.

of the resistive and pulsatility indices of the segmental and interlobar arteries using the standard technique.[20]

The resistive and pulsatility indices of the carotid and renal arteries were calculated according to the following equations [20]:

Resistive index = peak systolic velocity – end diastolic velocity/peak systolic velocity.

Pulsatility index = peak systolic velocity – end diastolic velocity/mean waveform velocity.

5. Statistical method

The collected data were coded, tabulated, and statistically analyzed using SPSS program (Statistical Package for Social Sciences) software version 20. Descriptive statistics were done for numerical data by mean, standard deviation, minimum and maximum of the range, while they were done for categorical data by number and percentage.

Analyses were done for quantitative variables using paired sample *t* test for parametric data within the group. Chi square test was used for qualitative data between groups when the cell contains more than 5.

Correlation between two quantitative variables was done by using Pearson's correlation coefficient: Correlation coefficient: weak (r = 0–0.24), fair (r = 0.25–0.49), moderate (r = 0.5–0.74), strong (r = 0.75–1).

The level of significance was taken at P value $\leqslant 0.05$.

6. Results

There is significant increase in FMD ($P < 0.001$) as well as the resistive ($P < 0.001$) and pulsatility ($P < 0.001$) indices of both the carotid and femoral arteries after ingestion of the test meal compared to before meal (Table 1). Systolic blood pressure ($P < 0.001$), diastolic blood pressure ($P < 0.001$) and mean blood pressure ($P < 0.001$) are also significantly increased after meal compared to before meal (Table 1). The level of plasma sodium is significantly increased after meal ($P < 0.001$) (Table 1). The percent of increase in each parameter are shown in Table 2.

There is no correlation between the percent of increase in blood pressure and FMD ($P = 0.894$), resistive ($P = 0.436$ & 0.616 for renal and carotid respectively) or pulsatility indices ($P = 0.747$ & 0.730 for renal and carotid respectively) (Table 3) which indicates that the increase detected in these parameters is independent of the increase of blood pressure.

Results of this study revealed significant correlation between the percent of plasma sodium increase and carotid pulsatility index ($P = 0.0001$) (Table 4 and Fig. 2).

7. Discussion

This study showed that only one meal containing high amount of salt impairs endothelial function 60 min after consuming it in healthy subjects. This meal also significantly increased pulsatility and resistive indices of both renal and carotid arteries. Although systolic and mean blood pressure were significantly increased after this high salt meal, no significant correlation between the percent of increase of blood pressure and percent of increase of FMD, PI or RI denoting that high salt meal exerts these deleterious effects independent on blood pressure increase.

High salt intake was documented to play a role in endothelial dysfunction, cardiovascular structure and function, albuminuria and kidney disease progression, and cardiovascular morbidity and mortality in the general population.[21]

The acute effect of salt in this study is consistent with previous study in young healthy volunteers which showed that salt loading of 250 mmol/d (14.7 g salt) for 5 days impaired the endothelium-dependent response to acetylcholine.[5] Furthermore, previous studies revealed that salt intake impairs endothelial function in few days.[5,9,22]

Results of this study revealed that high salt meal did these effects by mechanism rather than blood pressure rise. These findings also are consistent with previous studies which found the deleterious effect of dietary salt on endothelial function and arterial stiffness independent of blood pressure.[3,23,24]

Furthermore, Dickinson et al. studied the effect of high salt meal on augmentation index (AIx) as a measure of arterial stiffness and marker of endothelial function and concluded that AIx was significantly increased following the high sodium meal in spite of no significant effect on blood pressure.[25] Moreover, Cavka et al. confirmed that even one week of high salt

Table 2 The percent of increase of each parameter.

	Descriptive statistics
Renal RI percent	
Range	(0–16.95)
Mean ± SD	4.19 ± 3.28
Renal PI percent	
Range	(0–25)
Mean ± SD	4.81 ± 4.93
Carotid RI percent	
Range	(0–17.19)
Mean ± SD	3.44 ± 3.17
Carotid PI percent	
Range	(0–23.6)
Mean ± SD	6.61 ± 5.36
FMD percent	
Range	(0–34.1)
Mean ± SD	11.59 ± 7.17
SBP percent	
Range	(0–15.38)
Mean ± SD	1.93 ± 2.32
DBP percent	
Range	(0–11.84)
Mean ± SD	3.13 ± 2.62
Na percent	
Range	(0–2.96)
Mean ± SD	1.32 ± 0.83
MAP percent	
Range	(0–13.38)
Mean ± SD	2.58 ± 2.16

RI: resistive index, PI: pulsatility index, Na: plasma sodium level, FMD: flow mediated dilatation, SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean blood pressure.

Table 3 Correlation of blood pressure with different vascular parameters.

		Renal RI (%)	Renal PI (%)	Carotid RI (%)	Carotid PI (%)	FMD (%)
SBP percent	R	−0.146	0.057	0.054	−0.022	0.122
	P	0.280	0.671	0.694	0.869	0.363
DBP percent	R	−0.043	−0.100	0.073	−0.061	−0.118
	P	0.746	0.451	0.587	0.645	0.368
MAP percent	R	−0.104	−0.043	0.068	−0.046	0.018
	P	0.436	0.747	0.616	0.730	0.894

RI: resistive index, PI: pulsatility index, Na: plasma sodium level, FMD: flow mediated dilatation, SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean blood pressure.

diet significantly altered microvascular reactivity in young healthy normotensive and salt-resistant women that is pressure independent, but is a consequence of unique effect of high salt diet on endothelial function.[22]

One of the chief results in this study is the significant correlation between percent of plasma sodium level and percent of

Table 4 Correlation of plasma sodium with different vascular parameters.

		Renal RI (%)	Renal PI (%)	Carotid RI (%)	Carotid PI (%)	FMD (%)
Na %	R	0.058	−0.039	0.098	0.646**	0.185
	P	0.659	0.766	0.458	0.0001	0.151

RI: resistive index, PI: pulsatility index, Na: plasma sodium level, FMD: flow mediated dilatation.
** Highly siginificant.

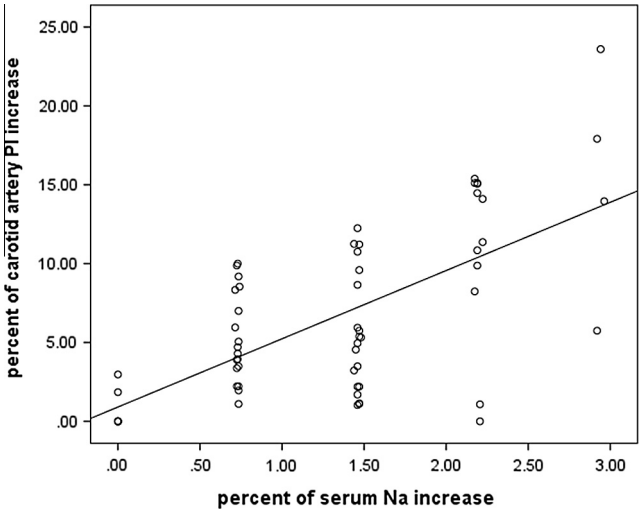

Fig. 2 Correlation between percent of increase of plasma sodium and increase of carotid PI.

increase in carotid PI that demonstrates the alteration in plasma sodium as a mechanism of these deleterious vascular effects of salt.

These findings are supported with previous two studies done on cultured endothelial cells[26,27] and have shown that increasing plasma sodium concentrations within a physiologic range stiffens human and bovine endothelial cells and reduces nitric oxide production.

The lack of correlation between percent of plasma sodium increase and other parameters included in this study namely FMD and RI denotes that these changes may be caused by several other mechanisms. Previous experimental study found that salt loading increases the activation of sympathetic nervous system in hypertensive rats.[28] Moreover, increased plasma renin activity[29] in the post-prandial phase may increase peripheral vascular resistance and may mediate decreased vasodilatation in vascular beds. Furthermore, it was demonstrated that short-term high salt intakes have been shown to similarly produce reductions in nitric oxide[30] and increase asymmetric dimethylarginine (ADMA) production (an endogenous nitric oxide inhibitor)[31]

8. Conclusion

High salt intake may acutely impair vascular function in different vascular beds such as endothelial dysfunction and increased carotid and renal arteries stiffness. These changes

occurred independent of the increase of blood pressure. This study detected that increase of plasma sodium plays a role in these changes.

9. Limitation

A limitation of the current study was that repeated postprandial measurements of FMD, PI, and RI are needed at longer intervals such as 90 min, 120 min and so on to detect the time needed for these parameters to regain its pre-prandial values.

Conflict of interest

We have no conflict of interest.

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